Joschka Bischoff, Kai Nagel

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Impact assessment of dedicated free-floating carsharing parking

Joschka Bischoff and Kai Nagel
Transport Systems Planning and Transport Telematics
Technische Universität Berlin
Salzufer 17-19
10587 Berlin
Email: bischoff@vsp.tu-berlin.de

***Abstract*—Free-floating carsharing (FFC) has become an established mode of transport in many cities world-wide and may help to reduce private car ownership in densely populated urban areas. However, parking FFC vehicles in residential areas is often problematic and this reduces the overall attractiveness of such systems. In this paper, a simulation based assessment is proposed to evaluate the impact of designated FFC parking spaces in a residential area in Berlin. For this, FFC vehicles and their users are integrated into an existing MATSim transport model that takes into account explicit parking search. Results suggest, that the creation of designated FFC parking spaces may help to increase the share of that mode in the area significantly and at the same time reduce private car usage.**

I. Introduction

In recent years, free-floating car sharing (FFC) systems were established as a new transport mode in cities in Europe and around the world. The ease of renting vehicles on demand using modern communication technologies allows an – often – profitable operation of fleets. In some cities, several thousand vehicles are operating already. The question, if at all, and how effectively these systems can help to reduce private car ownership in inner-city areas has been raised both by researchers and policy makers. This debate also is often accompanies by the question whether FFC systems should be supported by the public by providing certain advantages. These could include free or reduced parking costs for FFC vehicles, discounts for public transport users using FFC, as well as designated curbside parking spots. Especially the last point is heavily discussed, as it typically goes hand in hand with a reduction of parking spots for car users.

In this paper, we simulate the impact of a transformation of public parking space into parking facilities designated to car sharing vehicles using MATSim (Multi Agent Transport Simulation). [1] This allows to evaluate the effect on the overall mode choice and parking search durations for a study area in Berlin.

In the following section, an overview of related literature is provided. In section III, the simulation methodology is presented and the simulation setup and its relation to the real-world is described in section IV. This is followed by a presentation of results.

II. Related work

Car sharing systems have gained popularity over the last decades, with more and more cities offering both station based and FFC systems. [2] The impact of carsharing membership and usage on private vehicle ownership is widely discussed by many authors. A recent study for Germany assumes that FFC systems may reduce car ownership by 7 %, while the usage of station based systems decreasing ownership even further. [3] For the United States and Canada, one car sharing vehicle may replace 9 to 13 private vehicles. [4] The aforementioned studies all suggest a positive influence of carsharing on a declining vehicle ownership. Fleets of FFC vehicles may be battery electric, since range constraints do not apply to most users. Partly designated car sharing charging facilities, which would double as car sharing parking locations, may have also help to increase electric vehicle and public charging infrastructure usage. [5]

Simulation based assessment of car sharing services has shown various use cases for different car sharing applications (one-way, round-trip and free floating) and operators. [6] This has been combined with parking choice simulation [7] using MATSim, where the results clearly suggest that FFC vehicles make better use of inner city parking locations in comparison to private cars. However, the actual parking search was not simulated, but rather a mental model for scoring parking choices was used. This approach is computationally fast, but does not include the effects of parking search on traffic and the explicit modeling of persons walking to and from their parking location.

The simulation of parking search behavior has been described very detailed. [8] However, these simulations do not offer a full-scale integration of parking into a transport simulation. On the other hand. parking choice modeling has been available as MATSim extension for a while [9], the actual simulation of parking search behavior, even if proposed earlier [10] by other authors, was only realized recently. [11] This is, however, a requirement for high-detailed simulation of dedicated parking infrastructure for carsharing vehicles.

Bringing together an approach for modeling car sharing trips, parking search behavior and the effect on private car usage has to our knowledge not yet been combined into an overall simulation model.

III. Methodology

In this study, MATSim is used as the simulation software. MATSim's [12] basic concept is the simulation of agents and their daily routines (or *plans*) that include activities (such as home or work) and trips that link these activity locations. At the end of a day, the plan is scored depending on its performance. Performed activities are generally scored positively, traveling negatively:

$$U_{plan} = \sum_{i=1}^{m} (U_{act,i} + U_{travel,i})$$

where m is the number of activities an agent has in its plan. $U_{travel,i}$ may be split up into subcomponents, depending on the trip's structure (e.g., walking to or from a car may be scored differently than the actual car trip, see section III-B). For the next day (or *iteration*), a set of agents may modify their plans (i.e., by switching departure times, modifying routes or changing the transport mode), while the majority of agents chooses to perform an existing plan from their memory using a multi-nominal logit approach [13]. After several iterations, this leads to a state of equilibrium.

A. Parking Search and FFC in MATSim

Using standard MATSim approaches, no parking search is performed by agents driving vehicles. Instead, a scoring constant may be added when traveling by car mode to parameterize such effects. Yet physically, the agent will travel directly using car from its origin to its destination. If explicit parking search is to be simulated, some adjustments to the simulation need to be made. These have been described in detail in a previous paper of the authors [11]. The basic principle relies on splitting up the car leg into several subsections: *a)* Determining vehicle location and walking there *b)* Unparking the vehicle *c)* Route calculation and travel to destination, including searching for parking *d)* Parking the vehicle *e)* Walking to destination. Most notably, routing and parking search occur on the fly and are not pre-computed before an iteration, since a vehicle's parking location is not known for each step of an iteration upfront. This on-the fly route calculation has been widely used in different contexts, mainly for taxi applications [14]–[16]. The vehicles' parking locations are stored centrally by a Parking Manager, which also keeps the locations in between iterations. Several parking search strategies have been implemented, in this paper a random search described in [11] is used. Data about the available amount of curbside parking space is stored as an additional information per network link for the study area. In areas where no data about parking spaces is available, the agent may park directly on its destination link.

Due to software related reasons, the existing integration of carsharing [7] in MATSim proved to be incompatible with this explicit parking search. However, implementing a free-floating car sharing system on top of the existing parking search module could be achieved relatively easily. At the beginning of the simulation, a certain set of FFC vehicles is deployed in the network. If an agent wants to depart using a FFC vehicle, the closest vehicle within a certain search radius is found and reserved and the agent starts walking to this vehicle (rather than its private vehicle). For the rest of the trip (unparking, cruise, basic parking search principle), the agent behaves the same way as with traveling by private car described above. Once an agent reaches its destination link and cannot find immediately a parking space, it navigates to the closest carsharing parking space in the region, if available. However, should a standard parking space be available before reaching the designated lot, the agent will park there instead. This behavior is expected to depict the reality, where guidance about designated parking lots (and, possibly, their availability) may be given by navigational devices in FFC vehicles, but the user may still prefer to park somewhere closer to its destination. Should no FFC vehicle be available, the agent switches to public transport and a penalty is added to the agent's score.

B. Mode choice assumptions

The disutility of traveling [17] by car or carsharing is defined:

$$U_{travel_{mode}} = C_{mode} + \beta_{mode} * t_{travel_{mode}} + \beta_{walk} * t_{walk},$$

where C represents a mode specific constant, that may be interpreted as the general cost of car ownership or the necessity of being a carsharing club member. β_{mode} is marginal utility of in vehicle travel time and $t_{travel_{mode}}$ the actual travel time. In addition, β_{walk} and t_{walk} represent these values for walking to and from the vehicle. In principle, a distant specific β_{travel} could be added as well. However, the pre-calibrated model does not use this factor and in the case of FFC, distance based pricing is not used in Germany. For other modes, the disutility is simplified to

$$U_{travel_{mode}} = C_{mode} + \beta_{mode} * t_{travel_{mode}}.$$

Mode choice assumptions in the model are made on per-trip base. This means, an agent may choose to do an outward trip using public transport and to return using a freefloating car sharing vehicle.

IV. Prerequisities

A. The MATSim model for Berlin

The model used in this paper is based on the MATSim model for the year 2008-2011 [18]. It has been used in several Berlin-related case studies for all kind of transport policies and is well calibrated [19]–[21]. The network contains about 98 000 road links and 37 000 nodes. This allows to depict all major and minor roads within the city boundaries as well as all bigger roads in the surroundings. The synthetic population depicts a typical weekday in Berlin. Agent activities over the day are plentiful and include typical work and leisure activities. In the original scenario, agents make use of all relevant transport modes. During the course of the day, some 16 million trips are made by all agents. These also include very short trips made by bike or walking. Traffic flow in the

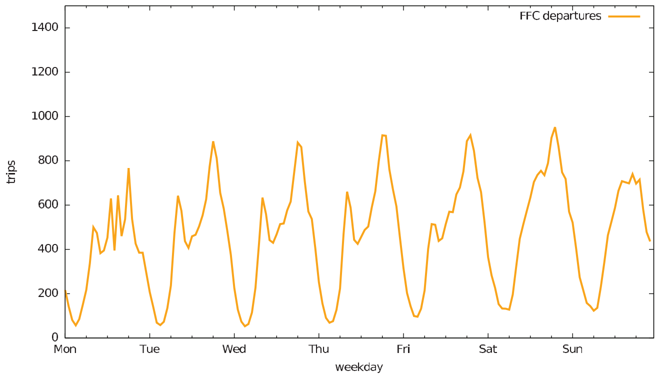

Fig. 1. Freefloating rentals on different weekdays in Berlin.

scenario is characterized by a morning peak which is followed by a constant amount of traffic flow during the day leading in a strong afternoon peak. The split of car and public transport trips in Berlin the city is roughly even, with both modes having a share of 35%. The scenario has been validated against car counting stations throughout the city.

B. Free-floating car sharing in Berlin

At the time of writing, there are three different operators offering FFC services in Berlin. Over 2 500 vehicles are available, which mostly serve the inner city area and densely populated areas around it. All three operators offer similar pricing, which generally lies between 0.25 € and 0.35 € per minute. There is no fixed monthly subscription fee nor a significant sign-up fee. Therefore, people tend to be a member of several operators at the same time. Preferences for one or the other operator will therefore not be taken into account in this study. In addition to these, several smaller operators offer station-based services throughout the city.

Usage of vehicles peaks during the afternoon, with a second, smaller peak in the morning, as also Fig. 1 depicts. On Saturdays, usage is more balanced throughout the day and overall the highest. Demand is generally lower on Sundays. The data is based on a data sampled collected in 2015 and shows the average number of FFC departures in Berlin of the two biggest operators [22].

C. Study area

The study area for the simulation runs in this paper is the quarter around Klausenerplatz in the Charlottenburg area in the western city center. Figure 2 shows the exact location. There are some 21 000 persons living in the quarter. The area consists mainly of residential buildings and narrow streets without much thru-traffic. Large arterial roads bordering to the north, south and west mark boundaries in everyday life, possibly influencing the parking locations of inhabitants.

Parking pressure in the area is high. A recent count performed during night hours concluded an overall parking occupancy of over 100 percent, meaning that all legal and many illegal curbside parking locations are in use. Overall, some 3 000 curbside parking locations are available. Parking

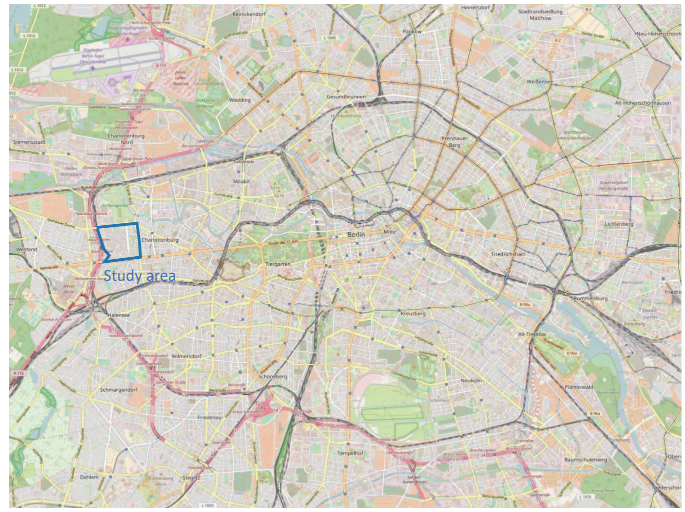

Fig. 2. Study area (OSM contributors)

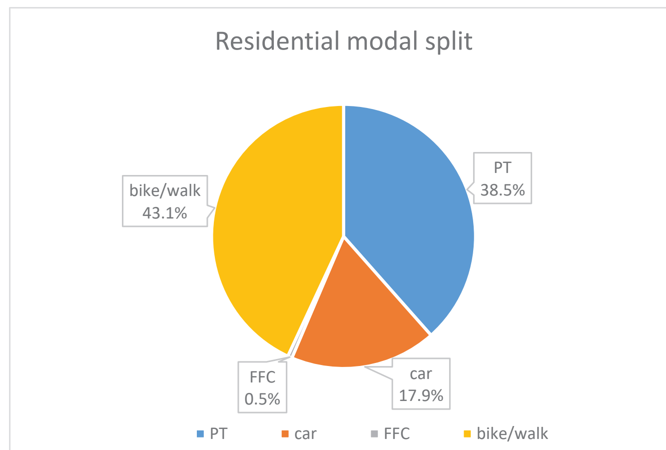

Fig. 3. Base case modal split of agents living in the study area

is free of charge in the whole area. Garages or private parking lots exist in non-significant numbers. Two supermarket parking locations are widely used for illegal nighttime parking.

All three FFC operators offer their service in the area.

V. Simulation Setup

A. Base case

FFC trips and the modeling of parking are not part of the initial Berlin model. Hence, a re-calibration of the base case is needed to reflect the current status quo. Since the explicit simulation of parking is computationally very demanding [11] and the area of interest is limited, the scenario was cut to include only those agents performing at least one activity within the study or its immediate surroundings. The travel times on links outside the study area were extracted dynamically from the original scenario, warranting travel times similar to the ones perceived in initial model.

As mentioned in section IV-B, the offerings of all three FFCS operators are somewhat similar in Berlin. Therefore,

TABLE I
PARAMETERS FOR FFC IN BASE AND POLICY CASE

	Base case	Policy case
$C_{mode_{FFC}}$	-24	-24
FFC Vehicles	2000	5000
FFC parking spaces	0	32

only a single operator is assumed in the model. Membership in a FFC club is randomly distributed among 5 000 agents who possess a driving license. The number is based on the actual users of one operator in the extended study area. A total of 2 000 vehicles is available throughout the city. The business area where FFC vehicles may operate depicts the current operators' area. To calibrate the base case, the C_{mode} parameter for FFC usage was modified in several iteration runs until the number of vehicles rented during the day was matching an observed count of about 300 weekday rentals.

A total of 150 iterations were run. Within each iterations, a subsample of agents (10 %) was allowed to change their travel mode for a single tripe between car, pt, walk/bike and FFC. The same number of agents was allowed to modify their departure times within a 15 minute time range. After 120 iterations, a further innovation of time and mode choice was witched off and the agents were only allowed to choose between their already existing plans in between iterations using a multi-nominal-logit model. This is a standard practice when working with MATSim.

The re-calibrated modal split of agents residing in the area is depicted in Fig. 3. Non-motorized modes and public transport already make up for roughly 80 % of all trips. Car usage is below 20 %. FFC trips accumulate to 0.5 % of all trips. Of the agents living in the area, 4 458 use a private car for at least one trip per day. For car and FFC users, it takes on average between seven and nine minutes to find a parking space and park a vehicle. Overall, 8 034 parkings were counted during the day.

B. Policy case

For the policy case, the output plans of the base case was used as the simulation input. A total of 64 common-use parking spaces were removed in the area. Half of them were turned into designated car sharing spaces and the other half was simply removed. These 32 carsharing spaces would be distributed in eight blocks of four vehicles. The assignment of four vehicles was found to be a good compromise by operators and would also allow installing charging infrastructure, should the vehicles be operated electric. The number of available vehicles is increased to 5 000[1], while the business area was kept the same. Table I summarizes the differences between base and policy case. The policy case was run for another 150 iterations using the same re-planning strategies as in the base case.

[1]This number is based on the operators' expectations in the upcoming years.

TABLE II
OVERVIEW OF KEY PERFORMANCE INDICATORS IN BASE AND POLICY CASE

	Base case	Policy case
Average parking search time	7:58 min	7:37 min
Vehicle miles traveled in area	19 827 km	17 719 km
FFC trips of residents	269	850
agents using private vehicles	4458	3949

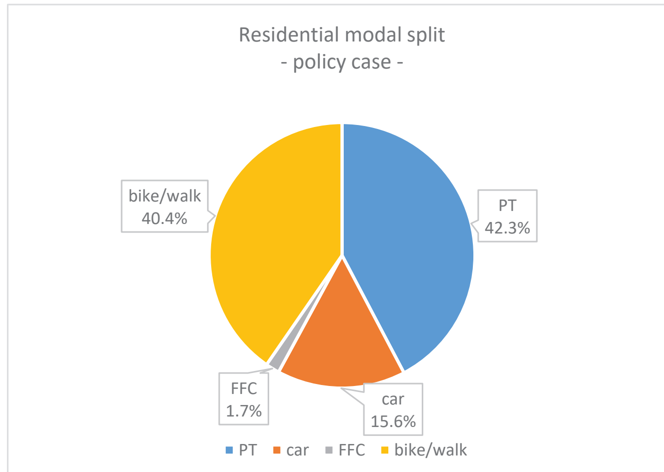

Fig. 4. Policy case modal split of agents living in the study area

VI. RESULTS

Simulation results for the policy case show a minor change of modal split in the area while parking search durations remain roughly the same. Some key performance indicators comparing both cases are summarized in table II.

A. Modal split change

The increased FFC fleet in combination with designated parking spaces increases the overall usage of that mode of agents living in the area to 1.7 % of all trips, or by more than three times. At the same time, the private car usage is reduced to 15.6 % (from 17.9 % in the base case) of all trips. Public transport and bike usage are overall slightly increased (with switched in between those two modes originating from simulational similarity of the modes). The overall change is depicted in figure 4. The effect of improved FFC offerings mainly attracts former car users, as the overall number of agents using a private car decreases to 3 949. This number may serve as one possible indicator of the potential amount of persons being willing to abandon car usage in their weekday routines.

B. Parking search duration and parking pressure

Arguably, the removal of parking spaces for private cars will increase the time spent on parking search for car users. At the same time, the observed shift from car mode towards other modes can help to reduce parking pressure and agents using FFC vehicles will benefit from decreased search times.

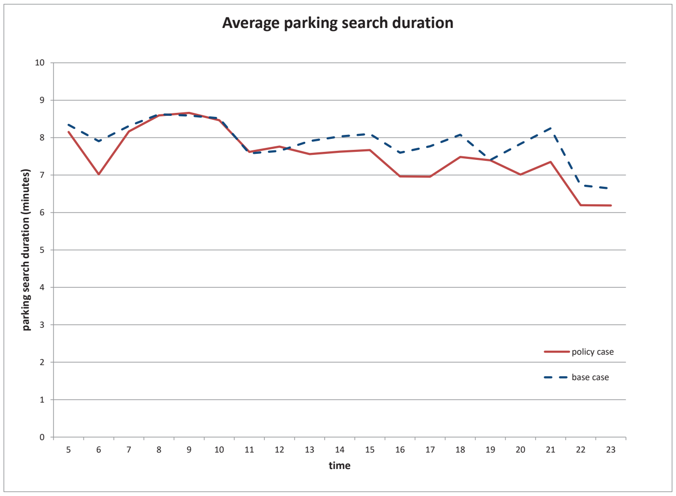

Fig. 5. Policy case modal split of agents living in the study area

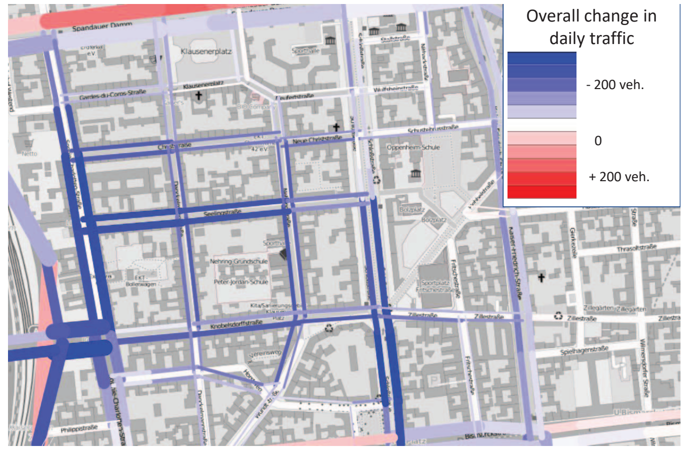

Fig. 6. Change in daily traffic volumes along the links in the study area

Both effects may compensate the loss in parking spaces. In Fig. 5, the average search time per hour is depicted over the day for both base and policy cases. On average, the time spent on parking search and vehicle parking varies between 7 and 9 minutes in the base case, with the all-day average being 7:58 minutes. For the policy case, the value is a few seconds lower during most hours of the day, with an all-day average of 7:37 minutes. However, during and immediately after the morning peak, search times are roughly equal in both cases. Most agents arriving at that time arrive while commuting to work in the study area. Their driving distances are often long, and the trip start locations make the use of other modes infeasible or impossible. Hence, this agent group will rather not consider a change of transport mode to be meaningful and stick to private car use.

C. Daily traffic volumes

The policy leads to an overall decrease in motorized traffic in the area. Especially along links connecting the study area with major roads in the north, south and west, the daily traffic decreases by more than 200 vehicles. While this is certainly not a big number, most of the area consists of very narrow streets, often with a speed limit of 10 km/h and a daily traffic volume of around 1 000 vehicles, so the change would be of significance. Fig. 6 shows the daily changes in traffic along the links in the study area. Overall, vehicle miles traveled by car are reduced from 19 872 km to 17 719 in the study area.

VII. Conclusion

In this paper, we combined an explicit parking search simulation model with free floating carsharing in a real-world scenario in Berlin. The effect on modal share of the residents in the area, their car usage and the parking seach duration of a possible introduction of 32 dedicated carsharing parking spaces was analyzed. The results suggest, that a reduction in private car traffic may be achieved with such a policy. The model also suggests, that former car trips would be partly replaced by both carsharing and other modes (bike, walk and public transport), leading to an overall decrease in car traffic. Search durations for parking lots may be reduced or will at least not increase.

It remains to be seen, if the positive influence we observe in the simulation can be transformed into a real-world setup. Several aspects, such as the exact position of parking locations for carsharing vehicles, the actual vehicle supply in the area and the real-world user acceptance may all limit the positive influence observed in the simulation.

Further research in this direction should include larger scale influences of such parking policies on a city level. Also, a combination with different parking policies may be of interest.

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